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Dear Sir:

# I. INTRODUCTION

This report summarizes the work carried out during the past six months on studies of the relations between the radar scattering properties of the moon and its surface features. The principle areas of study and investigation have been (1) continuation of the theoretical studies of the two-frequency radar experiment, (2) re-evaluation of the instrumentation and data reduction techniques used in the Doppler spectrum experiments, and (3) measurement of the scattering properties of the moon.

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## II. THEORETICAL STUDIES

### A. Two-frequency experiment

Theoretical investigations are being made on the correlation between two waves scattered from a rough surface (the lunar surface in particular) resulting from two incident plane waves at different frequencies,  $S_1$  and  $S_2 = S_1 + \Delta f$ . If the scattered waves at these two frequencies are represented by  $E_1^s = |E_1^s| e^{j\theta_1}$  and  $E_2^s = |E_2^s| e^{j\theta_2}$ , then the average of interest is  $\langle E_1^s E_2^s \rangle = \langle |E_1^s| |E_2^s| e^{j(\theta_1 - \theta_2)} \rangle$ , where both amplitudes and phase angles are random variables. Averages may be ensemble averages over a set of rough surfaces or time averages where the illuminated surface is moving slowly, as is the case with the lunar surface. The average to be computed from experimental measurements of the lunar surface is  $\langle |E_1^s| |E_2^s| \cos(\theta_1 - \theta_2) \rangle$ . Theory predicts that for a rough surface whose height is distributed according to a Gaussian second probability density function, the covariance function mentioned above varies as a function of the frequency separation  $\Delta f$ , according to the factor  $e^{-2\Delta k^2 \sigma^2}$ , where  $\Delta k = \frac{2\pi \Delta f}{c}$  and  $\sigma$  is the rms height of the rough surface. This result is independent of the form of the surface height correlation coefficient chosen. For a rough surface whose height is distributed according to a probability function somewhat different from

Gaussian (a modified Bessel function form), the factor which contains frequency separation is  $\frac{1}{(1 + \frac{4}{3} \Delta k^2 \sigma^2)^{3/2}}$ , a form not significantly different from that for the Gaussian for  $\Delta k^2 \sigma^2 < 1$ .

There are three objections behind the two-frequency studies. (1) To evaluate such experiments as a means of measuring mean square height of an unknown rough surface. Thus far no theoretical study has shown any effective method for obtaining information about the mean square surface height. (2) To obtain estimates of the form of the surface height second probability density function. (3) To study a somewhat different aspect of the effective communication bandwidth of the moon. [ Thus far measurements have been made only of amplitude correlation of two frequencies, i. e.,  $\langle |E_1^s| |E_2^s| \rangle$ , and such measurements have shown that this average drops to 1/2 of its initial value at frequency separations of about 2 - 4 kc. It is expected that the average  $\langle |E_1^s| |E_2^s| \cos(\theta_1 - \theta_2) \rangle$  will not fall to 1/2 until the frequency separation reaches 200-400 kc.

#### B. Doppler Spectrum Experiment

A re-evaluation of the instrumentation and data reduction technique used in the Doppler spectrum experiment have been completed. As a result improved instrumentation and data reduction techniques have been incorporated into the experiment. Computer programs have been written

for computing the position of the moon, the overall doppler frequency, and the Doppler spread due to the libration of the moon. Recently obtained data has been recorded undetected by down-converting to a low audio frequency. As a result both sides of the power spectrum will be maintained, rather than obtaining a folded, one-sided spectrum. The spectrum will be unaltered by the detection process. The power spectrum will be correlated with the "Doppler strips" on the moon and the maximum Doppler spread as obtained from the spectrum curve compared with the computed value. Using the results derived in reference 1, it will be possible to compute the average backscatter cross section per unit projected area.

#### C. Beam-width experiment

A joint experiment is being conducted between Ohio University and Ohio State University to measure the beamwidth of the moon. The interest in this experiment arose when in the initial stages of the program the moon was used as a target to obtain a crude boresight of the transmitting antenna. It was noticed that the signal levels did not fall off as rapidly as expected when the transmitting antenna beam was swept across the target. The preliminary results from this experiment indicate that the beamwidth is considerably greater than the predicted results. Further investigations of this phenomenon are needed to validate the present results.

### III. EXPERIMENTAL STUDIES

The work on the experimental phase of the program has consisted of instrumentation design for the various experiments and the measurements of the scattering properties of the moon. The frequency control equipment has been modified to incorporate the rubidium vapor frequency standard from which all frequencies in the system are synthesized. Frequency control accuracies of approximately 5 parts in  $10^{11}$  are maintained throughout the system. For the case of the Doppler spectrum experiment all phase-locked loops in the system have been removed and the Doppler tracking is accomplished on a programmed basis using data computed on the IBM 7094 computer. This technique reduced the possibility of contaminating the spectrum by the phase-locked loop characteristics. The same technique is being used on the two-frequency experiment.

A large quantity of data has been obtained from the Doppler spectrum, two-frequency, and polarization experiments. Arrangements are being made with Dr. Gaugler and the Goddard Space Flight Center to convert the analog data into a digital format. Computer programs have been completed to process the digital data.

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IV. PROPOSED PROGRAM FOR THE REMAINDER  
OF THE YEAR: May 1965 - October 1965

The program for the remainder of the year will involve the following work:

1. Continuation of the Doppler spectrum measurement as a function of the liberation rate of the moon.
2. Continuation of the two-frequency measurement as a function of liberation rate and frequency separation.
3. Continuation of the beam spreading characteristics of the moon.
4. Interpretation of the results from all of the lunar radar experiments

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#### REFERENCES

1. Compton, R. T. , Jr. , "The Solution of an Integral Equation for the Lunar Scattering Function", report number 1388-8, 1 April 1963, Antenna Laboratory, Ohio State University Research Foundation, prepared under Grant Number NsG-213-61 with National Aeronautics and Space Administration.